

Status of MiniBooNE

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MiniBooNE is a neutrino oscillation experiment now running at Fermilab. The experiment will search for $\nu_\mu \rightarrow \nu_e$ oscillations in order to make a conclusive statement about the yet-unconfirmed evidence for oscillations presented by the LSND experiment. Preparations for the start of running were completed over the summer of 2002, and MiniBooNE observed its first neutrino events in late August.

1. LSND EVIDENCE

The Liquid Scintillator Neutrino Detector ran at the Los Alamos Neutron Science Center over the years 1993 to 1998. Using the accelerator's 800 MeV proton beam, the experiment studied neutrinos coming from the decay $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ of muons at rest and from the decay $\pi^+ \rightarrow \mu^+ \nu_\mu$ of pions in flight. The muon decay at rest (DAR) process allowed a search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance via the reaction $\bar{\nu}_\mu p \rightarrow e^+ n$; neutrinos from pion decay in flight (DIF) provided a search for $\nu_\mu \rightarrow \nu_e$ appearance via the reaction $\nu_\mu C \rightarrow e^- N$.

The LSND detector was a cylindrical tank of 167 tons of mineral oil doped with a small amount of scintillator viewed by 1220 photomultiplier tubes. It was positioned approximately 30 m from the beam target area. For the 1993-95 running period the primary proton target was a water target, and in 1996-98 the target was made mostly of tungsten. The neutrino yield from the water target was higher, so that about 59% of the total DAR flux and 62% of the total DIF flux came from the 1993-95 period.

The DAR process yields neutrinos with energies up to the 52.8 MeV decay endpoint, and the DIF process produced ν_μ up to 300 MeV. The detector uses Cherenkov light for electron particle identification. The reaction $\bar{\nu}_\mu p \rightarrow e^+ n$ is observed by correlating the electron track with the 2.2 MeV gamma ray that follows from neutron capture on free protons in the liquid, $np \rightarrow d\gamma$.

LSND has presented results periodically. Analysis of 1993-95 DAR data produced an excess above backgrounds of $51.0^{+20.2}_{-19.5} \pm 8.0$ events, corresponding to an oscillation probability of $(0.31 \pm 0.13)\%$ (combined statistical and systematic errors) [1]. The DIF data from the same period yielded an excess of $18.1 \pm 6.6 \pm 4.0$ events, and an oscillation probability of $(0.26 \pm 0.11)\%$ [2].

In 2001, LSND presented final results using all of its data, combining the $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$ searches into a single analysis, and employing new event reconstruction with better spatial resolution [3]. A total excess of $87.9 \pm 22.4 \pm 6.0$ events was observed in the $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ search, corresponding to an oscillation probability of $(0.264 \pm 0.081)\%$. The common event selection was optimized for the DAR region below 60 MeV, and was therefore less effective than the previous DIF analysis in removing background events above 60 MeV. This analysis found no significant signal in the DIF energy region, where the observed excess was $8.1 \pm 12.2 \pm 1.7$ events.

The Karlsruhe Rutherford Medium Energy Neutrino experiment at the ISIS facility of the Rutherford Lab also searched for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations using $\bar{\nu}_\mu$ from μ^+ decay at rest [4]. The experiment employed a 56 ton segmented liquid scintillator detector located about 18 m from the beam target. The 1997-2001 run, known at KAR-MEN 2, did not observe an excess of events, finding 15 events while expecting a background of 15.8 ± 0.5 events. However, KARMEN 2 only had the sensitivity to rule out a portion of the LSND allowed parameter space. A comparison

*To appear in Proceedings of the 31st International Conference on High Energy Physics (ICHEP02) Amsterdam, 24-31 July 2002.

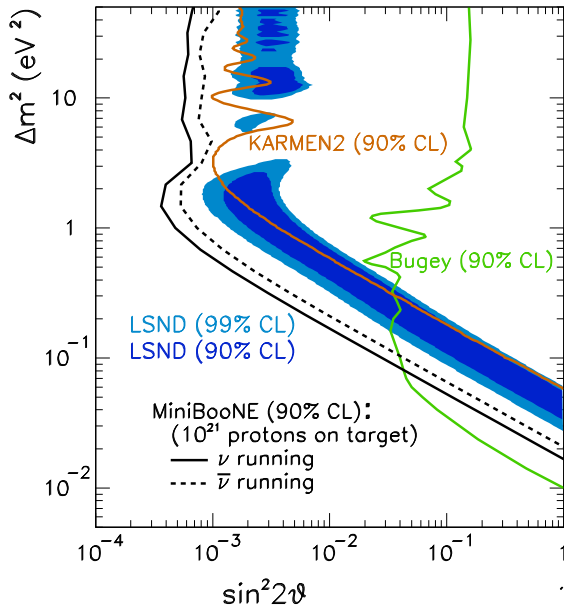


Figure 1. The LSND 90% and 99% C.L. allowed regions compared with the 90% C.L. exclusion contours from KARMEN 2 ($\bar{\nu}_\mu \rightarrow \bar{\nu}_e$), Bugey ($\bar{\nu}_e \rightarrow \bar{\nu}_\mu$), and the expected MiniBooNE contours using a ν_μ or a $\bar{\nu}_\mu$ beam.

of the favored LSND oscillation parameters with the KARMEN 2 limit is shown in Fig. 1. A combined statistical analysis of LSND and KARMEN 2 finds regions of oscillation parameters compatible with both experiments [5].

The LSND neutrino mass difference, $\Delta m_{LSND}^2 > 0.1 \text{ eV}^2$, is distinct from those indicated by oscillations of solar and atmospheric neutrinos [6]. This poses the problem that three neutrino masses cannot explain the three Δm^2 's. Proposed solutions include consideration of a sterile neutrino, supersymmetry, CPT violation, or lepton number violating muon decay [7]. In addition, the relatively high neutrino mass would contribute to the question of dark matter. It remains important to confirm or refute the LSND evidence, which MiniBooNE sets out to do.

2. MINIBOOONE OVERVIEW

At MiniBooNE we have begun collecting data to search for $\nu_\mu \rightarrow \nu_e$ oscillations. The ν_μ beam energy is in the range 0.5 – 1.5 GeV with a small intrinsic ν_e component and we will search for an excess of electron neutrino events in a detector located approximately 500 m from the neutrino source. The baseline to neutrino energy ratio is thereby similar to that of LSND, $L/E \sim 1 \text{ m/MeV}$, while neutrino energies are more than an order of magnitude higher.

The MiniBooNE neutrino beam is initiated by a primary beam of 8 GeV protons from the Fermilab Booster. The Booster is a reliable, high intensity machine, expected to run at least $2 \times 10^7 \text{ s}$ per year, while delivering 5×10^{12} protons per 1.6 μs pulse at a rate of 5 Hz to MiniBooNE. By this proton accounting, one nominal year for the experiment is expected to supply 5×10^{20} protons on target. The Booster has the capacity to provide protons for several Fermilab efforts, and the Booster continues to deliver protons to the Tevatron collider program.

A secondary beam is produced when the 8 GeV protons strike a beryllium target positioned inside a magnetic horn. At present, positively charged particles (mostly π^+ 's) from the target are focused forward by the single horn into a 50 m decay tunnel. The ν_μ beam is produced from the decay of these secondary particles. At a later time, the polarity of the horn can be changed in order to focus π^- 's to generate a $\bar{\nu}_\mu$ beam. Decay lengths of 50 and 25 m are possible through the use of two steel and concrete beam absorbers. One absorber is permanently positioned at the end of the decay tunnel. The intermediate absorber can either be lowered into the decay tunnel or raised out of the way. This ability to vary the decay length will provide a check of experimental systematics associated with ν_e contamination.

The MiniBooNE neutrino detector consists of 800 tons of pure mineral oil contained in a 40-foot (12.2 m) diameter spherical tank. A structure in the tank supports phototubes and optically isolates the most outer 35 cm of oil from the rest, turning the outer oil into a veto region that should stay quiet while a neutrino produces light only in the inner, main region. The main region is viewed

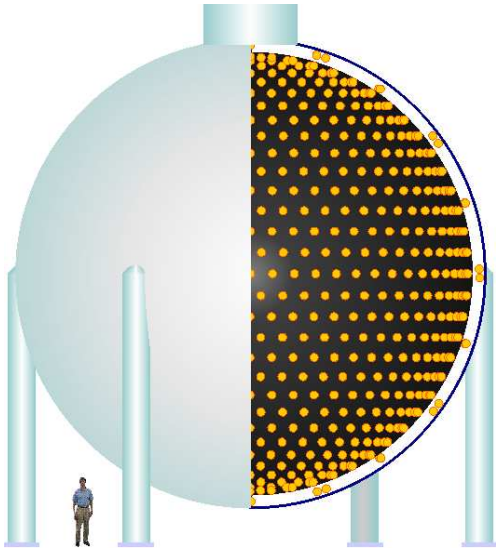


Figure 2. A schematic of the MiniBooNE detector. The cutaway shows the layout of 20-cm phototubes in the black main region and in the white veto region.

by 1280 20-cm phototubes, providing 10% photocathode coverage of the 445 ton fiducial volume. The veto region contains 240 20-cm phototubes mounted in pairs on the tank wall. A schematic of the detector is shown in Fig. 2. The center of the detector is positioned about 490 m from the end of the decay tunnel, and about 6 m below ground, corresponding to the level of the neutrino beam. An overburden of about 3 m of soil shields the detector enclosure.

The detector records the arrival time and total charge for each hit phototube. From this information, the track position and direction are determined. Electrons from ν_e interactions are identified via their characteristic Cherenkov and scintillation light signatures (the undoped oil scintillates modestly). Backgrounds to the oscillation search will be due to ν_e contamination in the beam and to the misidentification as electrons of muons and π^0 's produced in the detector. A display of one of MiniBooNE's first candidate neutrino events is shown in Fig. 3.

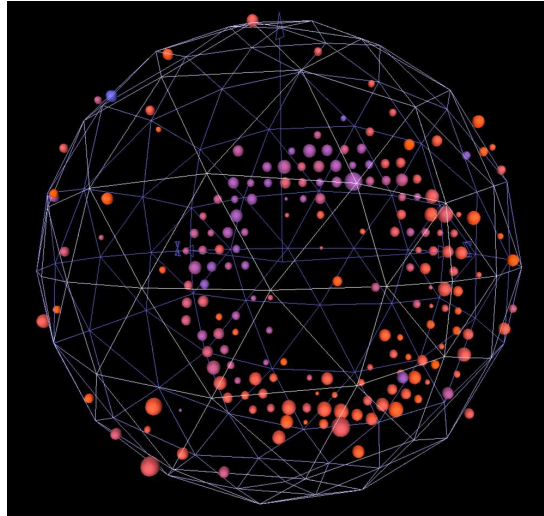


Figure 3. Event display of the muon signature from a candidate ν_μ interaction. Each dot represents a hit photomultiplier tube with the size proportional to the charge collected. This event comes from the set of the first few beam events observed by MiniBooNE in late August 2002.

3. BEAMLINE STATUS

Intense activity over summer 2002 focused on preparing the new 8 GeV proton beamline coming off of the Fermilab Booster to the MiniBooNE production target and secondary beam focusing horn. MiniBooNE started receiving proton beam on target in late August.

The focusing horn was designed to run at 5 Hz and for 200 Mpulses — a higher pulse rate and more pulses than any previous horn. In fall 2001 the horn was successfully bench-tested with more than 10 Mpulses making it already the world's most pulsed horn.

In summer 2002 the proton beam was commissioned in a few stages. In June protons were sent through the new beamline to a stop ahead of the MiniBooNE target area. Next the target and horn were installed and then removed in a dry run of procedures to be used for removing a damaged, radioactive horn. In July, without the target and horn in place, protons were sent through the tar-

get location, where a temporary multiwire beam monitor recorded the beam profile. The multiwire measurements were used to commission the final focus and to begin calibration of permanent beam position monitors (BPM's). In August the target and horn were reinstalled. The final configuration was modified slightly to include a multiwire just upstream of the target, which was used to complete the calibration of the target BPM's.

High intensity Booster operation is restricted by radiation limits, and beam losses will have to be reduced before MiniBooNE can reach its full beam intensity. In September the Booster was typically supplying 4×10^{12} protons per pulse. (Losses were observed to grow disproportionately when trying to run with 5×10^{12} protons per pulse.) By mid-September the pulses were arriving on target at 1 Hz. The experimental priority is to increase the repetition rate to 5 Hz (whereas 4×10^{12} protons per pulse is adequate). Operation above 1 Hz will become possible with the planned installation of a new extraction magnet in the winter. However, under current run conditions 5 Hz operation would exceed the radiation limits for beamline elements.

The Booster now supplies protons to both the TeVatron collider and to MiniBooNE. The start of MiniBooNE running has had negligible effect on collider operation.

4. DETECTOR STATUS

Installation of phototubes and of all related in-tank calibration and monitoring hardware was completed in September 2001. Filling the tank with oil started in December and completed in May 2002. The data acquisition electronics were commissioned over the same period, and phototube signals produced by cosmic rays and by a laser calibration system indicated the rising oil level.

The laser calibration system provides pulses to four light-diffusing flasks at various locations in the detector. The system is being used to determine phototube time offsets and time slewing corrections. Energy calibrations are being performed using electrons from the decay of stopped cosmic ray muons. In addition, a cosmic ray calibration system is being commissioned, which con-

sists of a hodoscope muon tracker above the detector with seven scintillator cubes (7.6 and 10 cm on a side) located under the tracker inside the detector. The system will provide the entering position and direction of cosmic ray muons. Cosmic rays that stop in a cube are a sample of muons with well-known path length in the detector, and will be used to calibrate the position, energy, and direction determination of the reconstruction algorithms.

5. PROSPECTS

As the first neutrinos were delivered to MiniBooNE the detector was ready to record them. It now remains to be seen how reliable and intense the beam will be. The beam intensity came up quickly, and within about three weeks of the start of the run, 4×10^{12} protons per pulse at a rate of 1 Hz were being delivered. The 1 Hz operation is currently limited by beamline hardware, which will be replaced this winter to allow 5 Hz operation. Work is ongoing to control beam losses so that 5 Hz beam operation is possible within radiation limits.

The experiment is currently running with a ν_μ beam. If oscillations occur as indicated by LSND, with 10^{21} protons on target MiniBooNE will observe an excess of several hundred electron events that will be significantly above background. The option will exist during the run to reverse the horn polarity to provide a $\bar{\nu}_\mu$ beam. The $\bar{\nu}_\mu$ beam will have a reduced flux, and the antineutrino cross section is smaller, but the backgrounds are also expected to be smaller, so that the experiment would retain significant sensitivity. MiniBooNE's expected 90% C.L. exclusion contours using a ν_μ and a $\bar{\nu}_\mu$ beam are shown in Fig. 1.

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